Causality, Relativity and the EPR Paradox

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Introductory Remarks: You have all read the paper (I hope). So what I propose to do is to sketch very broadly and omitting all the technical detail, the line of argument adopted in the paper, highlighting the more controversial points, which I am looking forward to hearing *your* views on.

The Problem Situation is that in some sense the EPR phenomenon in QM appears to involve nonlocality instantaneous action-at-a-distance and this is supposed to be ruled out by Special Relativity.

By EPR Phenomenon I mean the correlation properties of spatially separated systems in certain states involving the superposition of products of 1-particle wave functions. These are typified by the singlet spin wave function written as Eq (1) on p. 2 of the paper. This could describe for example the spins of two protons emerging from a low-energy (S-wave) scattering event (according to the Pauli Principle). Measurement of the spin-component of one particle apparently changes the state of the other particle in a nonlocal manner.

The first half of the paper (§§ 1–6) is concerned with analyzing the question
In what sense does EPR involve nonlocality ?

The second half (§§ 7–9) addresses the question
Does nonlocality conflict with Special relativity ?

5 min. I begin with two remarks

1.) Although Ψ_{singlet} is a N.R. wave function this does not mean we cannot use arguments based on Ψ_{singlet} to discuss conflict with S.R.
This is because Ψ_{singlet} is the correct form of a relativistic version of the 2-body spin wave function related to an appropriate frame of reference (c.o.m) where the 2-body system is chosen to be one in which motion relative to the c.o.m. is slow (low energy p-p scattering e.g.)

2.) In section 5, we show that no 'statistical' effects get transmitted at a distance. This means that our problem does not really arise in an ensemble or statistical interpretation of Q.M. It is only in the context of an attempt to impute states to individual systems that the difficulties are manifested.

* Gibbins on p16 gives an instance of what he calls a 'kind of non-locality' even on his ensemble approach. I would deny that this argument does actually demonstrate any sort of non-locality.

This is the manoeuvre whereby P-Gibbins ostensibly bypasses the problem discussed in my paper*. I am trying to ask the question: In an individual particle interpretation of QM are we involved in some counter-intuitive nonlocal action?

In order to proceed we distinguish 3 versions of the individual particle interpretation which I call A B & C.

This gives

3 views on observables not on an ensemble.

① A) Sharp unknown value
B) Unsharp or 'fuzzy' value
C) Undefined or 'meaningless' value.

cf. QM is not mysterious mysterious with new concepts like potentiality or latency and mysterious in recognizing limitations on the applicability of old concepts.

3 views on what measurement does

② A.) Pre-existing value revealed
B) Potential or latent value actualized
C) Undefined value becomes defined.

How is this change brought about?

(2a) 1.) Interaction with a physical instrument
2) Action of human consciousness

Bell locality: in the absence of causal influences recognized by current physical theories

Einstein locality: at a space-like separation between the two events — the measurement and the unsharp → sharp transition.

1.) The EPR Argument (1935) (§S.2)

10 min

This is an argument for the incompleteness of QM. It is based essentially on view B and shows that this view is incomplete in the sense that, even in non-eigenstates observables do have sharp values (not referred to in position B). So the argument invites us to turn to position A.
But the argument (given in S.2) involves a locality assumption.

2b Locality$_1$: unsharp → sharp forbidden.
(Distinguish Bell & Einstein sense of 'at a distance'.)

Bohr's response to EPR was to query whether we should not work ~~the~~ with view C and use

Locality$_2$: undefined → defined forbidden.

But other principles could be denied such as physical non-locality without

EPR showed that

2c QM + Locality$_1$ → incompleteness

i.e. QM → non-locality$_1$ or incompleteness

This is the Einstein dilemma.

But Bell showed (1964)
Completion → non-locality$_3$

where

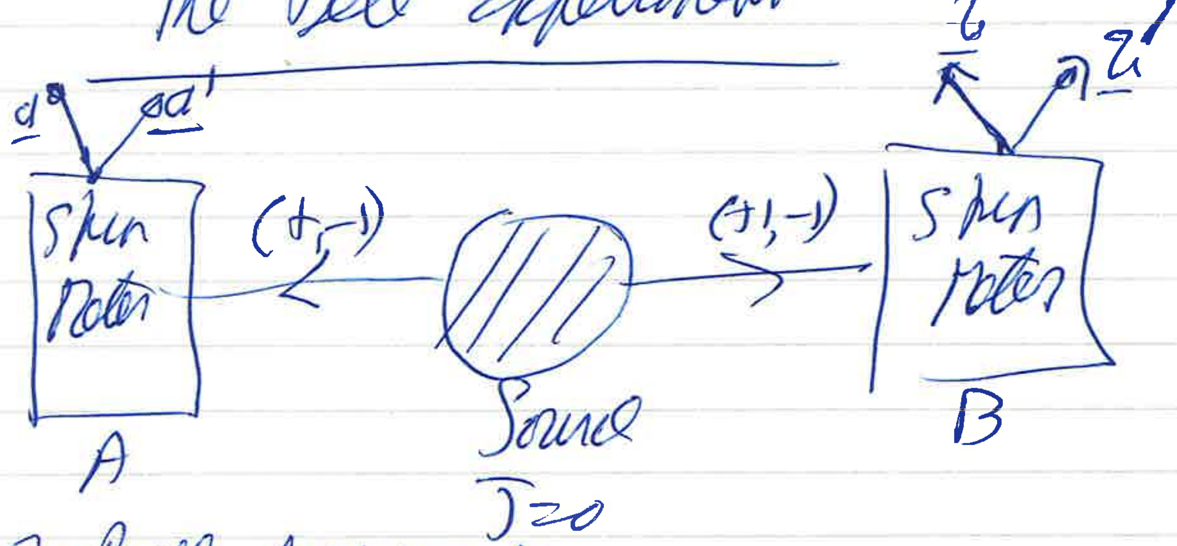
(2d) Locality$_3$: sharp → sharp prediction

15 min 2.) The Bell NonLocality Argument (BS 3)

I give this in a form adapted from Eberhard (1977)

The Bell Experiment

(3)


a
a'
b
b'
Spin Meter
Spin Meter
(+1,-1)
(+1,-1)
Source
J=0
A
B

The Bell Argument ~~shows that~~

(3a) Locality$_3$ → Bell Inequality which is contradicted by QM (and by experiment)

20 min

3.) The Stapp-Eberhard Approach (§4)

⑦ Locality$_4$: classical state of macroscopic object cannot be altered 'at a distance'.

⑧ The Principle of Local Counterfactual Definiteness (PLCD)

Result of an unperformed experiment has a definite result which does not depend on the setting of a remote piece of apparatus.

⑨ But in an indeterministic situation PLCD is suspect.

Contrast 1) clock striking as I raise my hand

2) An atom decaying as I raise my hand.

4) Statistical Nonlocality (§5)

25 min

⑪ no statistical effects produced at a distance — tagging information at the wrong location — Oxford lecture, room in Chelsea example.

— Impossibility of the 'Bell telephone'

5) Is locality violated in EPR?

(11a)

Violation \ View	Loc_1	Loc_2	Loc_3	Loc_4	Loc_5
A	no	no	yes	yes	no
B	yes	no	no	no	no
C	no	yes	no	no	no

Violation of locality, may allow peaceful coexistence with SR according to Shimony (1978).

Finite Signal Principle

upper limit to the velocity with which a signal can propagate relative to an inertial reference frame.

6.) In the second half of the paper I consider the arguments for reconciling tachyons with SR.

§7. Identifying SR with the Invariance Principle (IP) physicists predict the possibility of tachyons on the basis of SR. Impossibility of tachyons is identified with a First Signal Principle FSP.

We criticise the Einstein argument (1905) that IP → FSP

Instead we discuss the Grünbaum argument (cf also Salmon & Reichenbach)

PIP → FSP

where PIP is the Philosophically grounded Invariance Principle (I also discuss how causal loop paradoxes can be dealt with using the Reinterpretation Principle – RIP).
In §8 I give a new version of the causal theory of time which does allow tachyons. (But compare Malament (1977)) It hinges on the fact that a to-and-fro tachyon signal cannot be identified unambiguously (i.e. in a frame-independent manner) with a genidentical process.

I explain the confusion in the Grünbaum – Sjödin – Salmon account between the properties of tachyons which satisfy Lorentz-invariant equations

and what I call superluminal phenomena which do not.
Superluminal phenomena are inconsistent with SR both in the guise of IP and PIP, whereas tachyons are not. on my account!
In the final section of the paper I criticise the causal theory of time and suggest (perhaps controversially) that SR should be based directly on the IP.

Distinction too between spacetime and Relativity interpretations of SR (cf ~~Nerlich~~ (1981)).

Concluding remarks

30min

In this paper I give no detailed account of how EPR nonlocality might be explained by tachyon field theory (which involves [illegible] problems of its own arising from the question of how to define the vacuum state). What I have tried to do is to state the basic problems in as clear as manner as possible and to explore the locus of peaceful coexistence between nonlocal features of QM and the constraints of SR. at the level of fundamental objections to such a possibility. [illegible] My conclusion is that many of the arguments dealing with these questions in the literature have overlooked essential features of the situation. The definitive resolution of this issue is one of the most challenging problems in current philosophy of physics

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